Simulation of a Dielectric-Rod Loaded Horn Antenna Using openEMS

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Previously, simulations of feed horn antennas were conducted using NEC2++, an electromagnetic field analysis program based on the Method of Moments (MoM). In this study, a dielectric-rod loaded horn antenna, which cannot be simulated using NEC2++, is analyzed using openEMS, an electromagnetic field analysis software based on the Finite-Difference Time-Domain (FDTD) method. The results confirm both the effectiveness of openEMS as a simulation tool and the practical advantages of employing dielectric loading.

Introduction

Simulations of various feed horns for parabolic antennas—specifically, 3-section conical horns, W2IMU horns, and Chaparral horns—have previously been performed using NEC2++ **[1] [2] [3]**. These conventional horn antennas achieve the radiation patterns required for optimal dish feeding by attaching horns or corrugated rings to the circular waveguide aperture.

On the other hand, a recent issue of DUBUS magazine introduced a practical example where a dielectric rod is inserted into a waveguide to shape the radiation pattern **[4]**. While the theoretical concept of radiation pattern shaping via dielectric loading was known from literature, practical amateur examples remain relatively uncommon. Since the author is currently acquiring proficiency in openEMS **[5]** as an electromagnetic simulation tool, the design published in DUBUS was selected as an instructive exercise for handling dielectric materials.

Benchmarking

To validate the simulation results, a benchmark test of openEMS was first performed using a well-documented baseline case. For this purpose, a "Profiled Dielectric Feed" consisting of a conical horn antenna loaded with a dielectric rod, as presented in literature **[6]**, was simulated.

Figure-1 defines the dimensions of this design, while **Figure-2** and **Figure-3** illustrate the simulation model of the entire antenna assembly and the standalone dielectric rod, respectively. Note that the dimensional parameters were converted to an operating frequency of f_0 = 10.48955 GHz from the original values, which were normalized to the wavelength. Although not visible in **Figure-2**, a dipole element is

positioned inside the circular waveguide to excite a mode equivalent to TE_{11} . The relative permittivity of the dielectric rod is set to ϵ_r = 2.5.

Figure-4 shows the radiation pattern calculated by openEMS. When compared with the reference radiation pattern in **Figure-5** (reproduced from the literature **[6]**), the main lobe geometry exhibits excellent agreement. However, while the envelopes of the side lobes show similar trends in both models, differences in their absolute levels are observed. Furthermore, the back-lobe level in the original reference is approximately −30 dB, whereas the openEMS results show a slightly higher level.

The exact cause of these discrepancies—whether they stem from the modeling methodology within openEMS or from simulation parameter constraints affecting numerical accuracy—has not been fully solved. Consequently, it is concluded that side- and back-lobe levels must be evaluated with caution. Based on these benchmarking outcomes, the following section places primary emphasis on the evaluation of the main lobe.

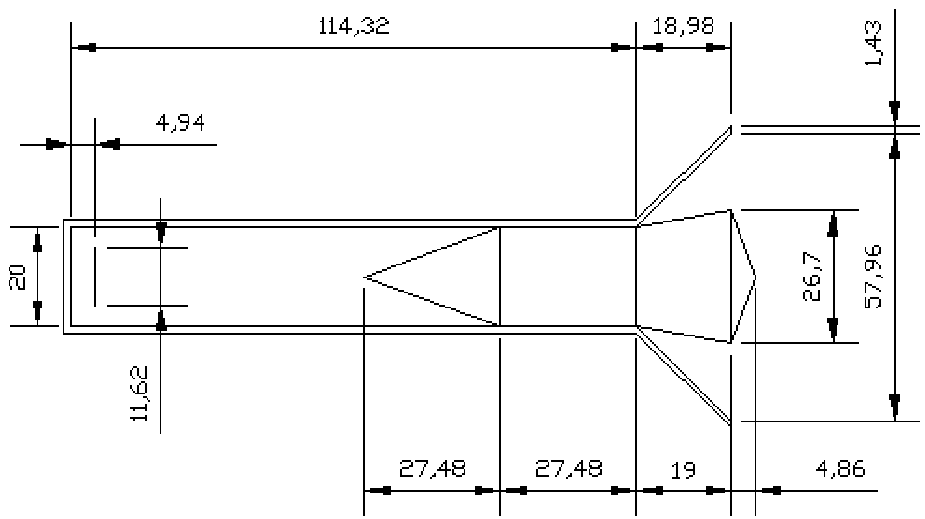

Figure-1: Dimensional definitions of the Profiled Dielectric Feed (adapted from **[6]**).

The design featured in DUBUS magazine **[4]** is a ground station antenna designed for the Es'hail-2 / QO-100 satellite. It features an integrated dual-band configuration where the 2.4 GHz uplink transmission is handled by a patch antenna, and the 10 GHz downlink reception is managed by a horn antenna consisting of a circular waveguide loaded with a dielectric rod. In this section, the dielectric-rod loaded horn antenna component is simulated independently.

The dimensions are defined in **Figure-6** (reproduced from the original article **[4]**). **Figure-7** and **Figure-8** display the simulation model for the complete antenna assembly and the standalone dielectric rod, respectively. Since the original text specifies that the dielectric rod is fabricated from Polyamide 6, a relative permittivity of $\epsilon_r = 2.5$ is assumed. Consistent with the benchmark model, excitation is provided by a dipole positioned inside the circular waveguide to approximate a TE_{11} mode.

To evaluate the influence of the 2.4 GHz patch antenna and verify the enhancements contributed by the dielectric rod, radiation patterns were simulated for three distinct configurations: a bare circular waveguide without the patch antenna, the horn antenna integrated with the patch antenna, and the final assembly featuring the attached dielectric rod. The calculated radiation patterns for each configuration are presented in **Figure-9**, **Figure-10**, and **Figure-11**.

The radiation pattern of the bare circular waveguide shown in **Figure-9** is characterized by a wide main lobe and elevated side- and back-lobe levels. The target application in the original article is a feed intended for an offset dish with an f/D ratio of 0.6. For an f/D = 0.6 reflector, the optimal −10 dB illumination angle required for the feed is approximately ±45 degree. Thus, the bare circular waveguide alone is clearly under-illuminating and mismatched as a feed. While employing a flared horn is the standard approach to matching the illumination angle to the offset dish, doing so would interfere with the characteristics of the patch antenna. Therefore, a dielectric rod is utilized to match the illumination angle while avoiding adverse effects on the patch antenna performance.

Conversely, the impact of the patch antenna on the horn antenna performance warrants investigation. In the radiation pattern for the combined waveguide and patch antenna configuration (**Figure-10**), the H-plane main lobe becomes somewhat nar-

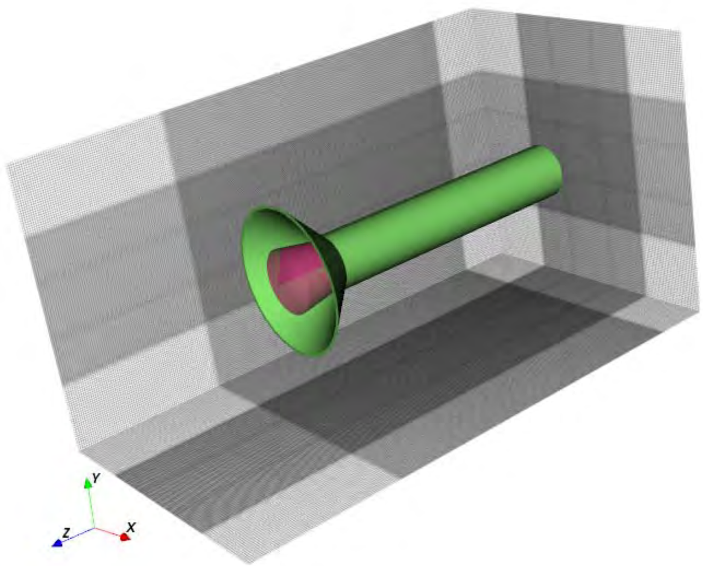

Figure-2: Simulation model of the Profiled Dielectric Feed.

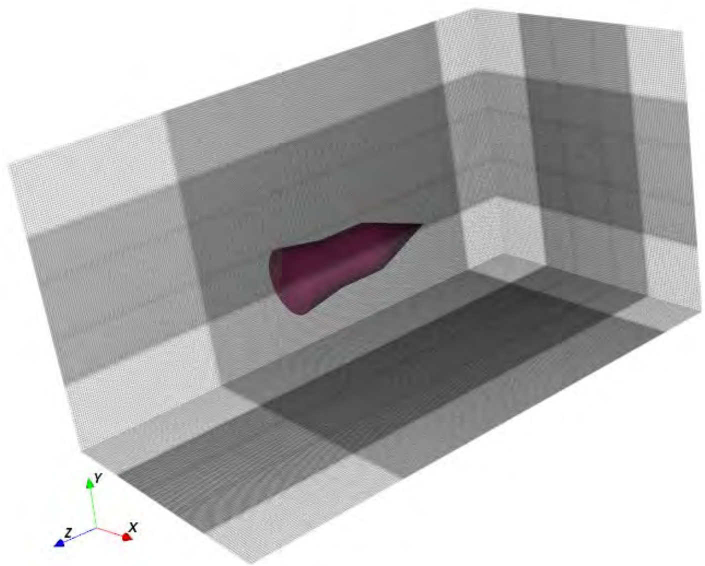

Figure-3: Dielectric rod of the Profiled Dielectric Feed.

rower, and the side- and back-lobe levels decrease, indicating a slightly favorable impact on feed performance. However, in the E-plane, the illuminated energy within the main lobe decreases, resulting in a degradation of the E/H-plane symmetry.

In the final configuration where the dielectric rod is attached, as shown in **Figure-11**, the main lobe narrows significantly. The −10 dB beamwidth achieves an illumination angle of approximately ±50 , which closely matches the requirements of an f/D = 0.6 offset dish. Additionally, the E/H-plane symmetry of the main lobe is noticeably improved. A reduction in both side- and back-lobe levels is also observed, demonstrating a clear enhancement in overall feed performance.

Conclusion

Simulations of a dielectric-loaded horn antenna were performed using the open-source FDTD-based software openEMS. The results demonstrated a generally solid correlation with previously established simulation data. In the practical design example, the simulation verified that the dielectric rod effectively optimizes the radiation pattern. Compared to a conventional flared conical horn, the dielectric rod offers a distinct advantage in terms of physical compactness. This makes it highly promising for multi-band feed applications such as the one evaluated. Nevertheless, because simulation is indispensable during the design stage, openEMS serves as an invaluable tool accessible to amateur radio operators.

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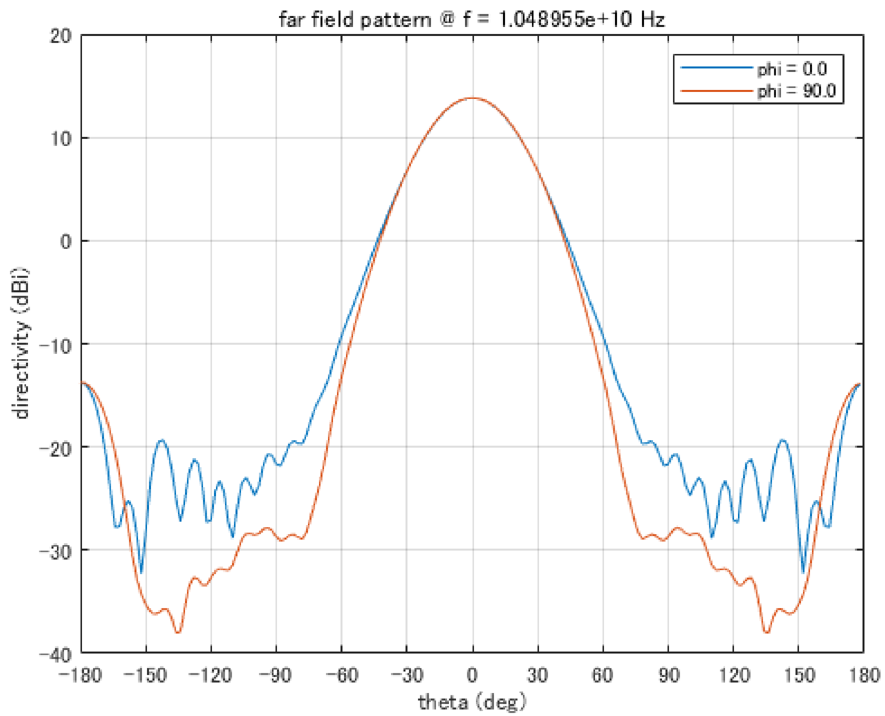

Figure-4: Radiation pattern of the Profiled Dielectric Feed computed by openEMS.

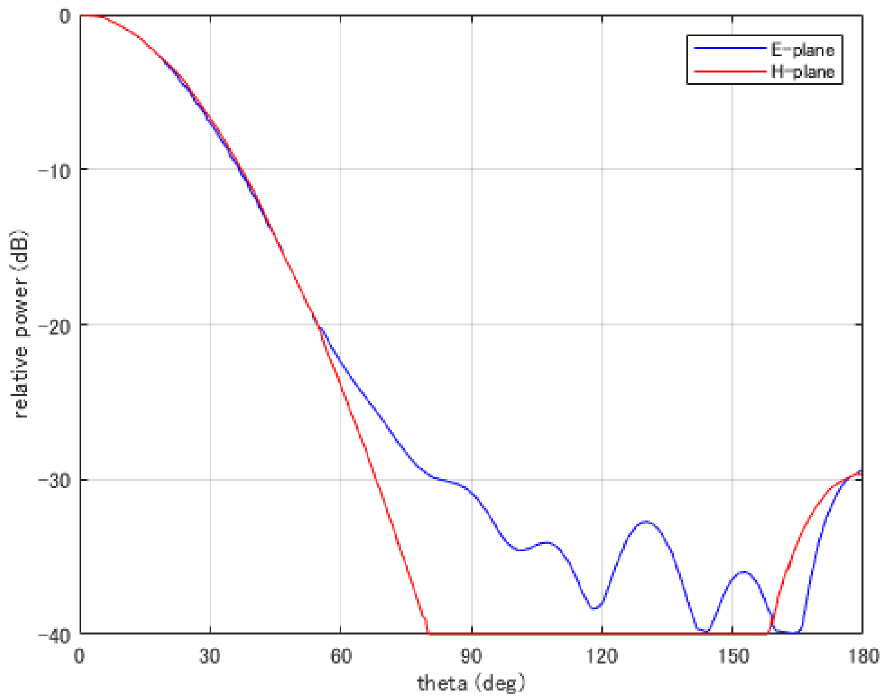

Figure-5: Radiation pattern of the Profiled Dielectric Feed (adapted from **[6]**).

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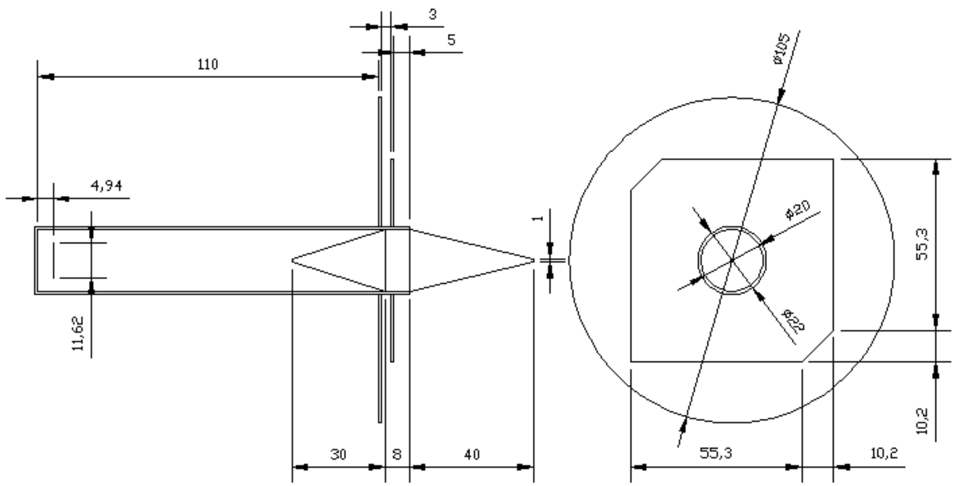

Figure-6: Dimensional definitions of the Simple Dual-Band Dish Feed (adapted from **[4]**).

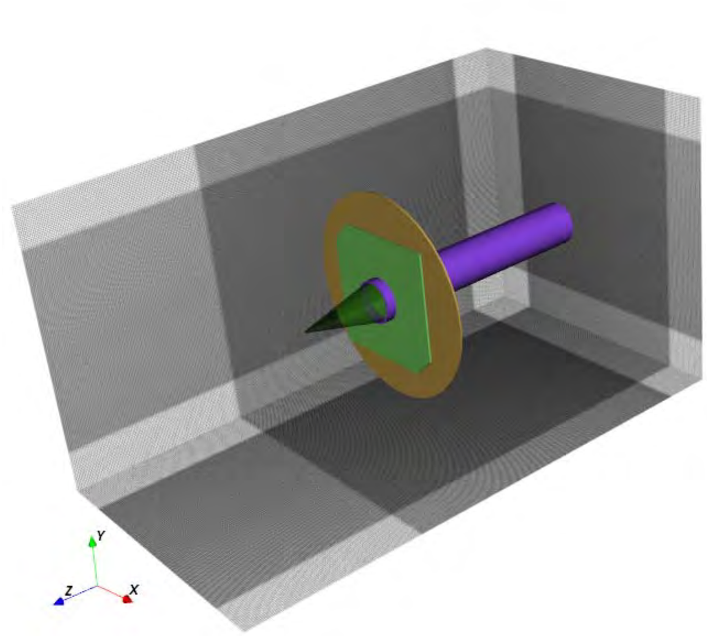

Figure-7: Simulation model of the Simple Dual-Band Dish Feed.

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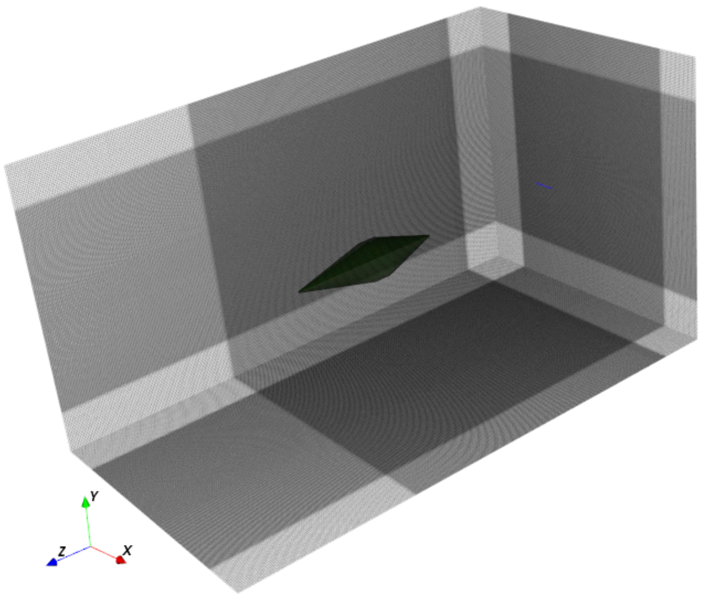

Figure-8: Dielectric rod of the Simple Dual-Band Dish Feed.

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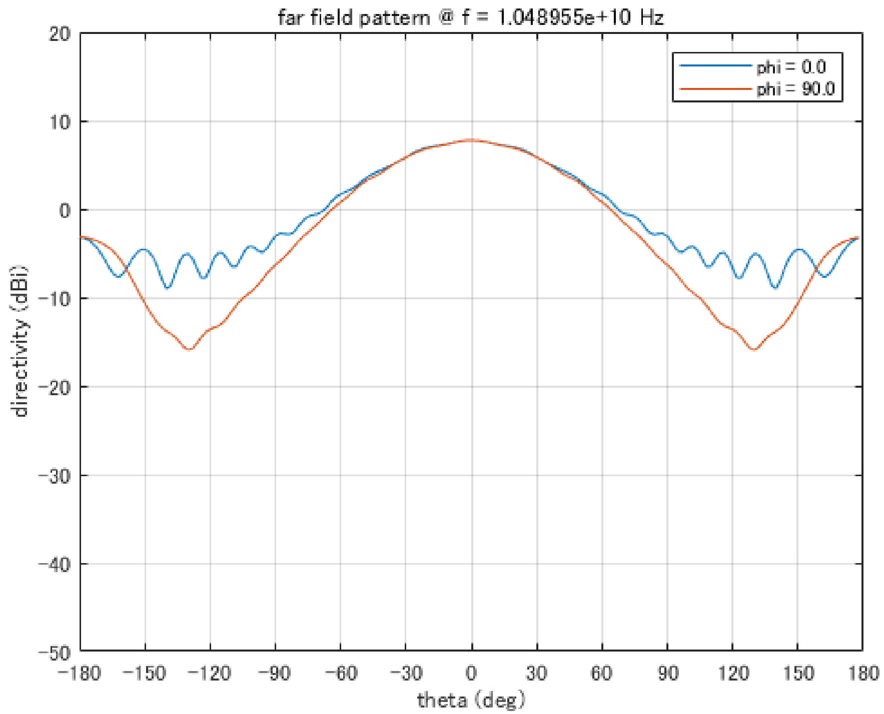

Figure-9: Radiation pattern of the Simple Dual-Band Dish Feed
(bare waveguide only).

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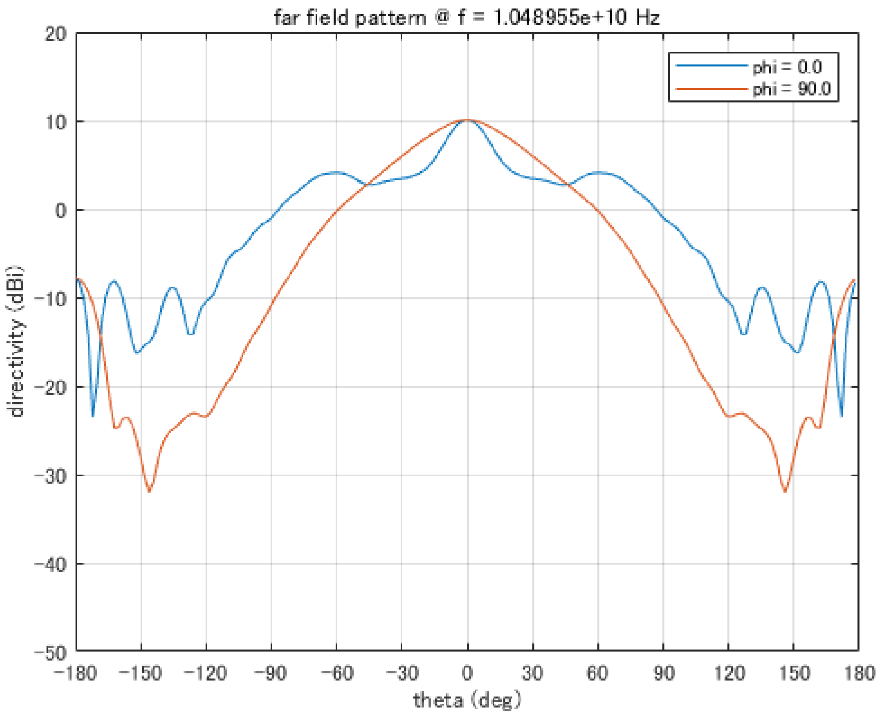

Figure-10: Radiation pattern of the Simple Dual-Band Dish Feed (bare waveguide with patch antenna).

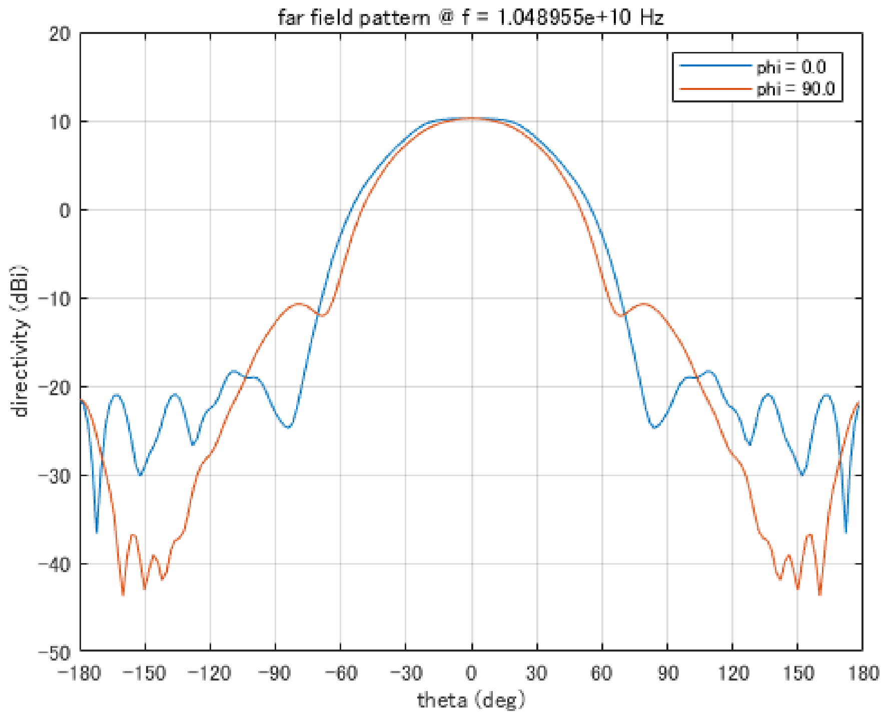

Figure-11: Radiation pattern of the Simple Dual-Band Dish Feed (with dielectric rod attached).